ARMY RESEARCH LABORATORY

A Barrel Straightness Measurement System for Medium Caliber

by Mark Bundy, Jim Garner,
Mark L. Kregel, and Mark D. Kregel

ARL-TR-4273 September 2007

NOTICES

Disclaimers

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-4273 **September 2007**

A Barrel Straightness Measurement System for Medium Caliber

Mark Bundy and Jim Garner
U.S. Army Research Laboratory
Weapons and Materials Research Directorate

Mark L. Kregel, and Mark D. Kregel
Kregel Technical Services, Inc.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2007	Final	Feb-Aug, 2007

4. TITLE AND SUBTITLE
A Barrel Straightness Measurement System for Medium Caliber

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Mark Bundy, Jim Garner, Mark L. Kregel, and Mark D. Kregel

5d. PROJECT NUMBER
AH80

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Battlefield Environment Division (ATTN: AMSRD-ARL-WM-BC)
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-4273

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
ARL-TR-4273

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Gun barrel straightness is a critical manufacturing requirement for all calibers. Precision laser-based photo diode systems have been developed and perfected for quick and accurate centerline straightness measurement of large caliber smooth bore barrels. However, an equivalent system for medium caliber does not exist. A reduced caliber not only means smaller mechanical and electrical components, but also that barrel rifling will be present. This presents an added challenge to the centerline measurement. Kregel Technical Services, Inc. and the U.S. Army Research Laboratory (ARL) have worked together to develop a fast and accurate system for measuring a rifled medium caliber barrel centerline. This report describes the measurement system and demonstrates how it works on 20-mm M197 test barrels.

15. SUBJECT TERMS
Subject terms are needed here! medium caliber, barrel, centerline, straightness, measurement

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Mark Bundy
a. REPORT	b. ABSTRACT	c. THIS PAGE	SAR	18	19b. TELEPHONE NUMBER (*Include area code*)
U	U	U			(410) 306-0975

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

1. Introduction

The importance of precisely measuring medium caliber barrel centerlines relates to the correlation between centerline straightness and weapon accuracy. In the large caliber 120-mm Abrams tank barrel it was shown conclusively that barrel straightness has a significant effect on gun accuracy (*1–3*). The dependence of accuracy on centerline straightness is presumed to hold true for all calibers. In support of this assumption for medium caliber barrels, Siewert (*4*) concluded his study of 20-mm ammunition dispersion from the Phalanx Gatling gun system by stating:

- monitoring bore straightness is critical to targeting success
- bore straightness can be critical for low dispersion, multi-barrel systems
- bore straightness has implications for single barrel weapons with mean points of impact (MPI) vs. aim point requirements when barrels are changed
- bore straightness of single barrel guns will influence MPI difference for projectiles with significantly different action times (e.g., armor piercing fin-stabilized discarding sabot (APFSDS) vs. high explosive (HE).

Historically, one of the simplest methods to determine overall barrel straightness is to conduct the so-called "drop test." A bore plug, of specified length and diameter (slightly smaller than the bore diameter), is dropped down a barrel. If it passes through, the tube it is considered acceptably straight.

Another method of determining bore straightness requires a certain level of interpretative skill. The barrel is visually examined by looking directly down the bore and inspecting the circularity of plane-wave light reflected off the side walls. The level of concentricity in the apparent light-rings is indicative of the bore straightness.

A more automated mechanical method of discerning barrel straightness, measures the roundness of the barrel's outer diameter at various down bore positions using a total indicator reading (TIR). This method can be accurate if the wall thickness is uniform; however, that cannot be assumed.

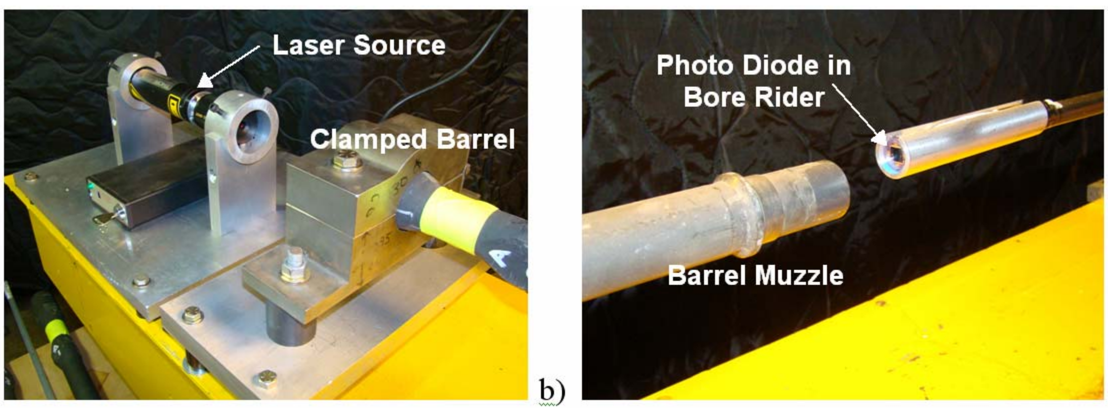
A more exact, albeit labor intensive way of measuring a medium caliber barrel is described by Siewert (*4*); wherein an external laser source was directed at a bore traversing photo diode. The photo diode was manually pulled down the bore of a 20-mm M61A1 barrel (a slightly longer version of the M197 barrel studied in this report). The detector's electrical signal generated by the impinging laser was manually converted into its lateral position (bore centerline) as a function of its longitudinal down-bore position.

2. An Automated 20-mm Bore Centerline Measurement System

The medium caliber measurement system described in this report is similar to the automated computer controlled system developed by Kregel Technical Services, Inc. (KTS), under contract to and working with the U.S. Army Research Laboratory (ARL) for the 120-mm M256Abrams tank barrel (ref. 5). The same developmental partnership was in place during this undertaking. Although this system was specifically designed for the 20-mm M197 barrel, with a bore length of ~1440-mm (~57 in.) it could be adapted readily to any medium caliber system.

2.1 System Hardware

The basic components of the system are the laser source, shown in figure 1a, and a photo diode mounted in a bore rider, in figure 1b. These fundamental components were also used by Siewert (*4*), as described above. However, this system is automated by the computer-controlled chain drive shown in figure 2, which is propels the bore rider up and down the bore, recording 171 centerline measurements (while on the move) in each traversal.



a) b)

Figure 1. Primary bore centerline measurement components, a) laser source directed into chamber end of barrel, and b) photo diode on bore rider entering muzzle end.

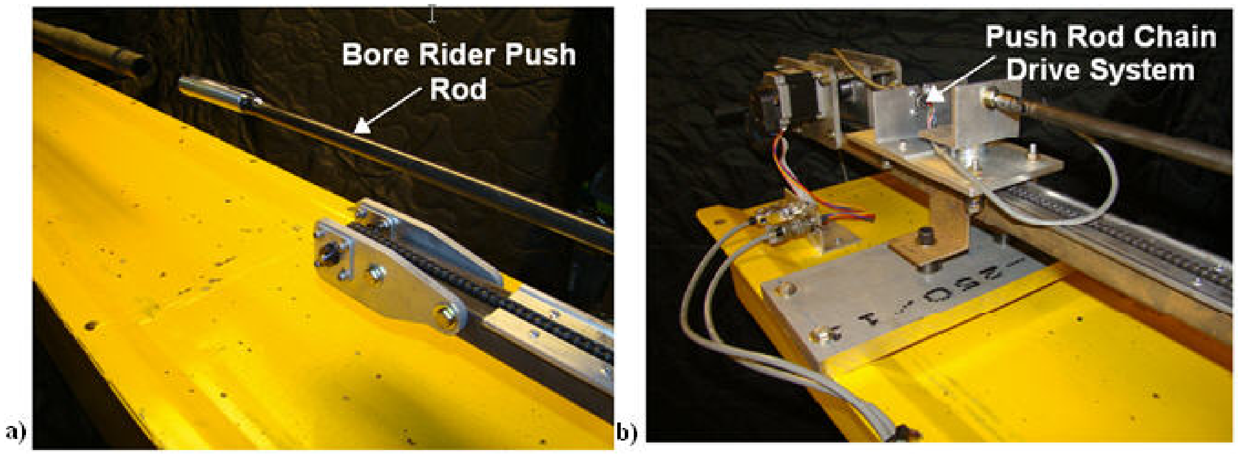


Figure 2. Chain driven bore rider system a) muzzle end, b) motor end.

2.2 Centerline Measurements

An example of three up- and down-bore measurements on a randomly chosen M197 barrel, denoted as barrel A1, is shown in figure 3. At first glance, it can be seen that the measurement is highly repeatability. Before commenting further, a word needs to be said about the coordinate frame of reference as used in figure 3.

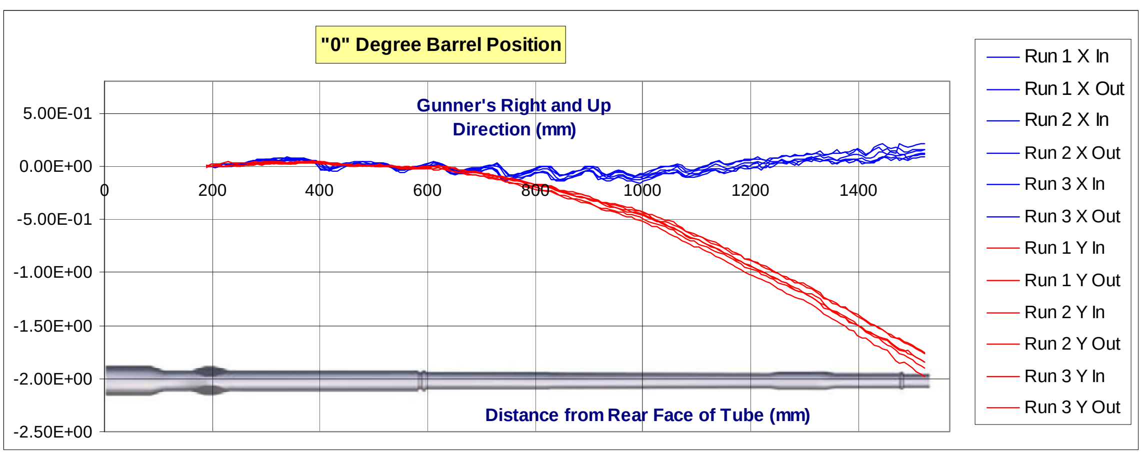


Figure 3. Three sets of centerline measurements on an M197 20-mm barrel, denoted as A1.

The horizontal axis (zero lateral deflection) in figure 3 is defined by a straight line drawn between two centerline measurement points. These two zero reference points are often taken to be the first and last measurements, which is the traditional coordinate reference frame used in specifying the acceptable manufacturing tolerance of large caliber guns. This “manufacturing” frame of reference is used by Siewert (*4*). However, the two zero-coordinate reference points used in figure 3, and within the remainder of this report, are chosen to more closely coincide with the nominal projectile axis during its early in-bore travel. In particular, the reference points are defined by the first measurable point from the origin of rifling and a point that is ~25% down-bore from this point. Although this designation is somewhat arbitrary, it provides a long

enough baseline to reduce the consequences of measurement error in the reference points themselves, while still preserving the identity of the baseline as the initial velocity direction of projectile motion. Figure 4 displays the PRODAS-predicted[1] velocity profile of the primary tactical M56A4 round of the M197 barrel. The mean projectile velocity over the first 25% of in-bore travel is ~50% of the muzzle velocity. The interpretive value of referencing the centerline to the early motion of the round is that it gives a relative indication of how abrupt the late motion (near muzzle) directional changes are in comparison.

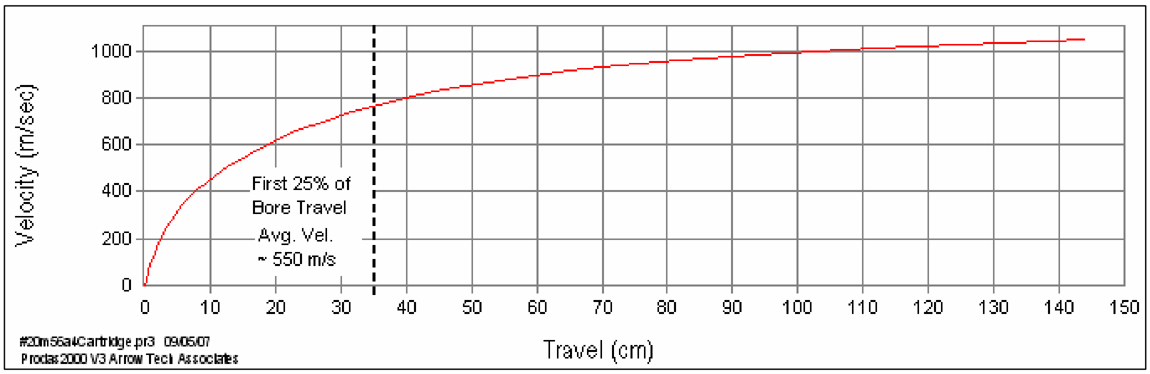


Figure 4. PRODAS prediction of in-bore velocity vs. down-bore travel for the M197 tactical round, M56A4.

Returning to a discussion of figure 3, this particular barrel is relatively straight in the horizontal plane, but has a downward bend in the vertical plane. To determine what part of this downward bend is due to gravity, the barrel is rotated 180° and remeasured, as shown in figure 5. Note the 180° horizontal centerlines are approximately the negative (mirror image through the horizontal axis) of their 0° counterparts. This indicates that there is virtually no horizontal bias (such as a horizontal push-rod force) inherent in the measurement system. Adding the 0° and 180° vertical-plane measurements and dividing by two, yields the gravity droop alone for the M197 barrel (held as shown in figure 1a). On the other hand, if the 180° vertical-plane measurement is subtracted from the 0° vertical-plane measurement and divided by two, it yields what is called the gravity-free barrel centerline. Both the gravity droop and the gravity-free A1 barrel centerline are shown in figure 6.

[1] PRODAS is a projectile design and analysis software package marketed by Arrow Tech Associates, Burlington, VT.

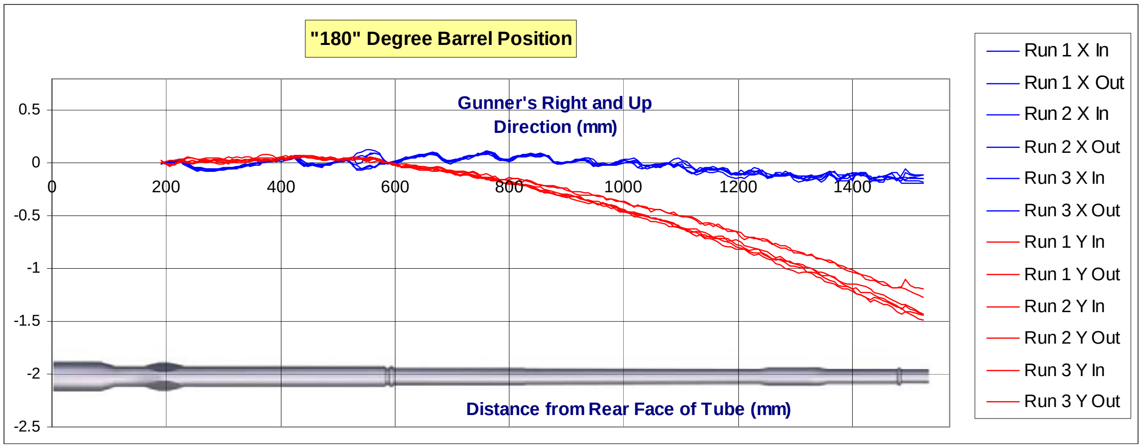


Figure 5. Three sets of centerline measurements on barrel A1 rotated 180°.

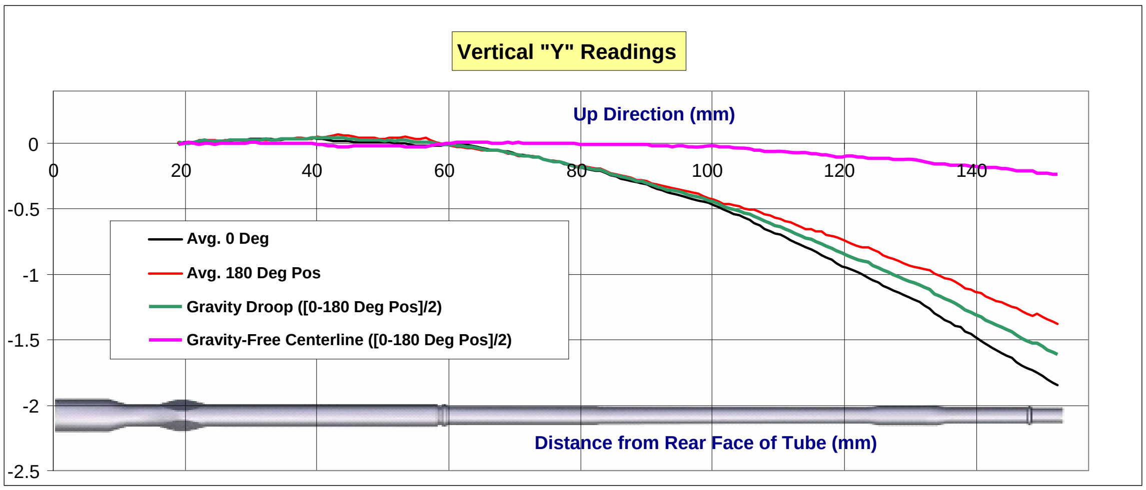


Figure 6. Average 0° and 180° A1 centerline as well as the average sum and difference.

It might be noted that the small amplitude oscillations that appear in the horizontal centerlines of figures 3 and 5 (0° and 180° barrel orientations, respectively) are thought to be because of the asymmetric surface contact of the bore rifling with the diode-affixed bore rider. The fact that there is a slight clearance between the bore rider and the bore allows the cyclic pattern of the rifling contact to move the bore rider, ever so slightly from side-to-side in the horizontal plane. Even though the same clearance exists in the vertical plane, it is speculated that the slight weight bias of the measurement system (bore rider and push rod) force the bore rider to stay in contact with the lower bore surface; therefore, rifling-induced oscillations do not appear in the vertical plane centerline.[2]

[2] These hypotheses are based on experiments with trial bore rider shapes and clearances.

The subject of bore rider and push rod weight brings into question the effect this weight might have on the overall vertical centerline measurement. In order to determine the effect and factor it out of the measurement, a dial indicator was placed under the barrel at five axially dispersed locations (32, 337, 654, 972, and 1200 mm from the muzzle face of the tube). The changes in the dial indicator readings were noted with and without the measurement system in the bore at the same axially dispersed locations. The downward deflection of the barrel resulting from this procedure is noted in figure 7. Also shown is a polynomial fit to the displacements, which can henceforth be used to factor out the weight of the measurement system.

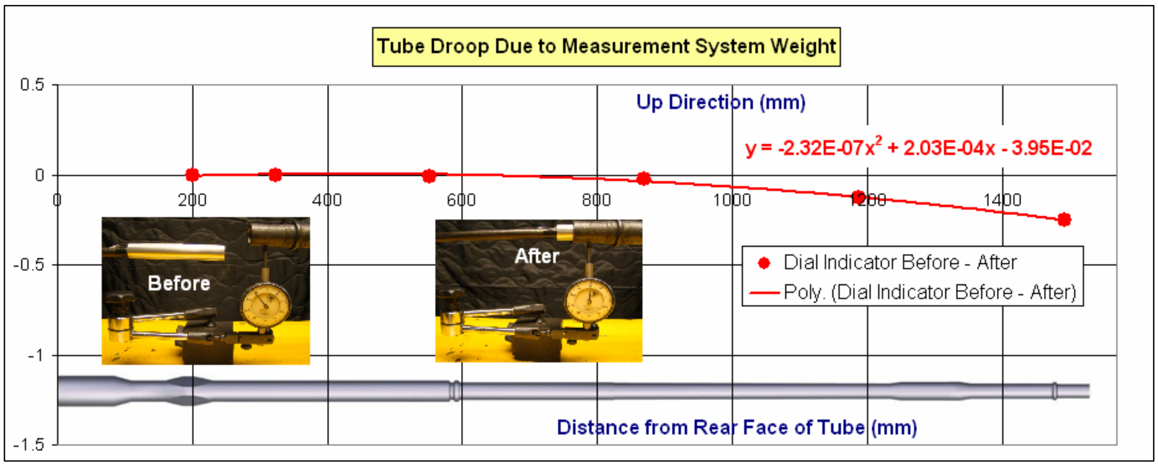


Figure 7. Effect of measurement system weight on tube droop.

2.3 Tube-to-Tube Variation in Centerlines

The centerline variation of barrel A1 (figures 3, 5, and 6) looks fairly benign. It is essentially straight in the horizontal plane, and were it not for the effect of gravity, figure 6 shows that it is fairly straight in the vertical plane as well. Is this level of uniformity typical of the M197 barrel?

Figure 8 shows the three trial average of three randomly selected barrel centerlines, denoted as A2 and A3, in addition to A1. These vertical-plane centerlines all have the effect of measurement system weight (figure 7) removed from their measurement data.

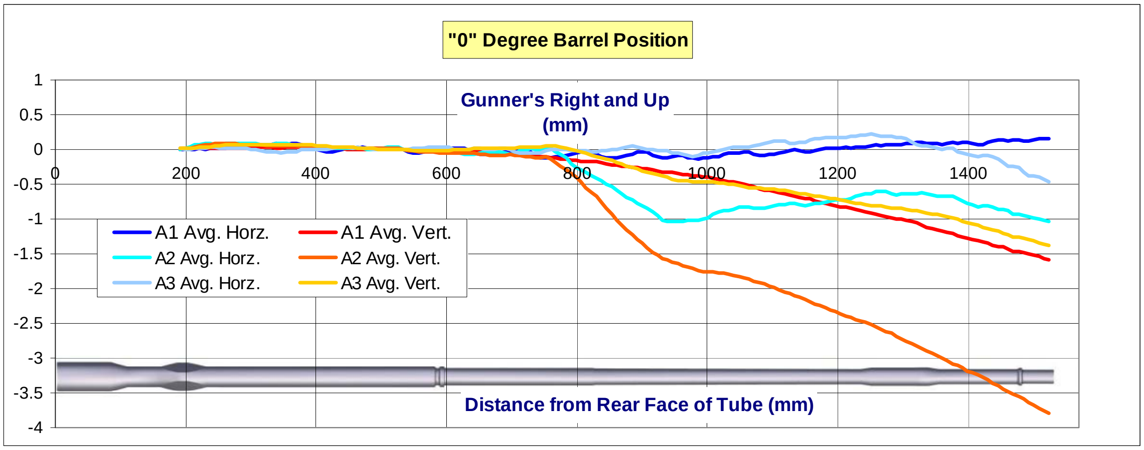


Figure 8. Tube to tube centerline variation in three M197 barrels.

As can be seen in figure 8, there is substantial centerline variation even though only three barrels were selected. For example, muzzle deviations in either plane rarely exceed 1.5 mm over the 4300 mm bore length of the 120-mm M256 Abrams tank barrel; however, barrel A2 has a muzzle variation of nearly 4 mm over a much shorter bore length of ~1400 mm.

Furthermore, the M197 barrel is not unique among medium caliber systems in that it can be inserted into the gun mount in any of three different orientations. Thus, if any of the barrels in figure 8 were removed and reinserted into the mount, without paying attention to preserving the original circumferential orientation, the horizontal and vertical centerline component of that barrel could be quite different. As an example, figure 9 shows how centerline A2 would change as the barrel is rotated through 90° increments.

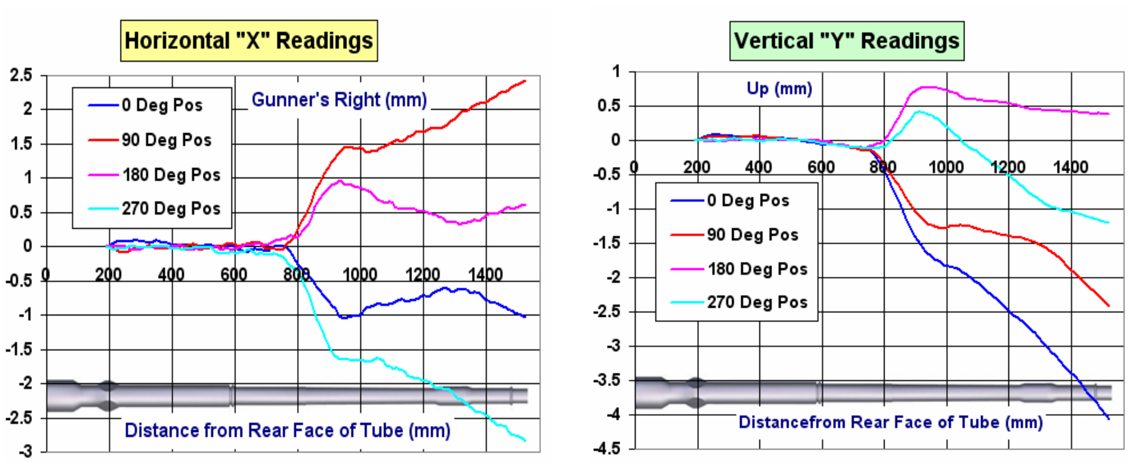


Figure 9. The effect of rotating a barrel, for example A2 on changes in the horizontal and vertical centerline profile.

3. Conclusion

The effect of gun barrel centerline on accuracy has been proven for large caliber barrels and recent testing indicates this appears true for medium caliber barrels as well. Preselecting, or perhaps reshaping, medium caliber barrels to obtain uniformity in centerline shape may be a long range goal for improving weapon accuracy. However, first it is necessary to demonstrate an ability to readily measure medium caliber centerlines, which previously was not the case. This report has shown that it is now possible to quickly and repeatedly measure medium caliber barrel centerlines. The results show several times more centerline variation in a shorter medium caliber barrel, the 20-mm M197, than observed in a much longer large caliber barrel, the 120-mm M256.

References

1. Bundy, M.; Webb, D.; Garner, J.; Newill, J.; Kaste, R.; Wilkerson, S.; Roy, W.; Durkin, P.; Pomey, A. *The Effects of Barrel Centerline Uniformity on the Fleet Accuracy of Training Ammunition*; ARL-TR-3324; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, Sept 2004. (UNCLASSIFIED)
2. Bundy, M.; Garner, J.; Webb, D.; Newill, J.; Kaste, R.; Wilkerson, S.; Roy, W. *Improved Service-Round Accuracy from Gun Barrel Reshaping and its War-Game Implications;* ARL-TR-3348; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, Oct 2004. (SECRET)
3. Bundy, M; Garner, J.; Webb, D.; Durkin, P.; Marrs, T.; Pomey, A. *Sensitivity of Weapon Accuracy to Barrel Centerline Uniformity*; ARL-TR-3947; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, Sept 2006. (UNCLASSIFIED)
4. Siewert, J. Optimized Gun Barrel Targeting Investigation, *Proceedings of the 2005 Guns and Ammo/Rockets and Missiles Conference*, NDIA, New Orleans, LA, Apr 2005. (UNCLASSIFIED)
5. Bundy, M.L.; Garner, J.; Kregel, M.L.; Kregel, M.D.; *Grogan, N. Quantifying the Influence of Measurement System Weight on the 120-mm M256 Barrel Centerline*; ARL-TR-4059; U.S. Army Research Laboratory; Aberdeen Proving Ground, MD, Mar 2007. (UNCLASSIFIED)

Acronyms

APFSDS	armor piercing fin-stabilized discarding sabot
ARL	Army Research Laboratory
HE	high explosive
KTS	Kregel Technical Services
MPI	mean points of impact
TIR	total indicator reading

Distribution List

No. of Copies	Organization
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	US ARMY RSRCH DEV & ENGRG CMD SYSTEMS OF SYSTEMS INTEGRATION AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
5	DIRECTOR US ARMY RESEARCH LAB IMNE ALC IMS US ARMY RESEARCH LAB AMSRD ARL CI OK TL (2 COPIES) AMSRD ARL CI OK T (2 COPIES) 2800 POWDER MILL RD ADELPHI MD 20783-1197
6	PM MAS ATTN SFAE AMO MAS MCC LTC K INSCO (3 COPIES) SFAE AMO MAS SMC LTC M BULTER R KOWALSKI K KO BLDG 354 PICATINNY ARSENAL NJ 07806
2	US ARMY TACOM ARDEC ATTN CCAC AMSTA AR CCL C G FLEMINIG J HIRLINGER BLDG 65 PICATTINNY ARSENAL NJ 07806-5000
1	NSWC CRANE ATTN D LONG BLDG 2521 300 HIGHWAY 361 CRANE IN 47522-5001

No. of Copies	Organization
1	TACOM ATTN AMSTA LC CSAU M SCHNEIDER 1 ROCK ISLAND ARSENAL ROCK ISLAND IL 61299-7630
1	TACOM ATTN AMSTA RI SES C JOHNSON BUILDING 25 ROCK ISLAND ARSENAL ROCK ISLAND IL 61299
1	ARROW TECH ASSOCIATES INC ATTN J SIEWERT 1233 SHELBURNE RD STE D 8 SOUTH BURLINGTON VT 05403
2	ATK ORDNANCE & GROUND SYS ATTN R WATERFIELD ATTN B GLANTZ 3309 NORTH RESEDA CIRCLE MESA AZ 85215
2	ROBBINS AIR FORCE BASE ATTN WR ALC/LMMW LT T MAGOUL J YOUNG SUITE 221 460 RICHARD RAY BLVD ROBBINS AIR FORCE GA 31098
1	ROBBINS AIR FORCE BASE ATTN WR ALC/LMEW F BARNES SUITE 221 460 RICHARD RAY BLVD ROBBINS AIR FORCE GA 31098
1	MICHAEL J FISCHER 2000 W NASA BLVD M/S K04 219 MELBOURNE FL 329048

No. of Copies	Organization
1	DIR US ARMY RSCH LABORATORY ATTN AMSRD ARL CI OK TECH LIB BLDG 4600 APG MD 21005-5066
1	AEC CSTE AEC CCE W ATTN PAULETTE SMYERS BLDG 4120 APG MD 21005-5066
4	ABERDEEN TEST CENTER ATTN CSTE DTC AT TD J WALLACE CSTE DTC AT FP L R SCHNELL CSTE DTC AT WF A T MARRS M FEINBERG BLDG 400 APG MD 21005-5066
1	AMSAA ATTN AMSRD AMS C R CHANDLER BLDG 392 APG MD 21005-5066
2	RAYTHEON MISSILE SYSTEMS ATTN MATT ATKINSON 6201 STRAWBERRY LANE LOUISVILLE KY 40214
1	PAUL SCHAUER P.O. BOX 20 NASA TEST AND EVALUATION CONTRACT LAS CRUCES, NM 88004

No. of Copies	Organization
5	AMSAA ATTN AMSRD AMS CA G DRAKE R FRANKLIN R DUMER AMSRD AMS SA D PAYNE G CASTLEBURY BLDG 367 APG MD 21005-5066
14	DIRECTOR US ARMY RESREARCH LABORATORY ATTN AMSRD ARL WM B D LYON C CANDLAND AMSRD ARL WM BC J NEWILL P PLOSTINS M BUNDY (3 COPIES) J GARNER (2 COPIES) B GUIDOS P WEINACHT AMSRD ARL WM BF S WILKERSON AMSRD ARL WM SG T ROSENBERGER AMSRD ARL WM TC R COATES APG MD 21005-5066
2	GENERAL DYNAMICS ARMAMENT AND TECHNICAL PRODUCTS (GDATP) JOANN KRAMER MICHAEL ROY 128 LAKESIDE AVE. BURLINGTON VT 05401

TOTAL: 56 (55 HCs and 1 Electronic)